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SUMMARY

Background

The physical demands of U.S. Navy occupations cause injuries and illness. This association has been documented for back injuries. Physical demands probably contribute to other health problems as well, but these associations have not been documented.

Objective

This study was undertaken to explore a wider range of health problems to determine which were related to occupational physical demands. It was hypothesized that physical demands would be related to the frequency of accidents, musculoskeletal disorders, and inguinal hernias. The ultimate objective was to estimate the total impact of occupational physical demands on health.

Approach

Occupational physical demand ratings (PDRs) obtained from senior enlisted personnel for 57 entry-level U.S. Navy occupations were used to measure physical demands. Previous research had demonstrated that these ratings were valid indicators of the occupational requirements for physical exertion. Ratings for reasoning, communication, reaction time, and dexterity demands were included to determine which health effects were specific to occupational physical demands. Hospitalization rates for 13 major illness categories and 28 subcategories within those major categories were obtained from the Epidemiological Interactive System (EPISYS). Correlation procedures were used to determine which illness criteria were related to occupational demands. Regression procedures were used to translate those associations into estimates of the number of hospitalizations arising from physical demands.

Results

Initial analyses established that the cognitive and psychomotor demands had a diffuse pattern of association with the health criteria. The average absolute value of those associations ($r = .237$) provided a reference correlation for evaluating the hypothesized correlations. PDRs were strongly related to accident rates ($r = .627$), musculoskeletal disorders ($r = .594$), and inguinal hernia rates ($r = .594$). PDRs also were strongly related to cellulitis rates ($r = .600$), alcohol abuse rates ($r = .493$) and alcohol intoxication rates ($r = .643$). Each of these associations was significantly larger than the reference correlation.

The effect of occupational physical demands on health was estimated using accidents, musculoskeletal disorders, inguinal hernia, and cellulitis as the relevant health outcomes. The PDR regression weights obtained from multiple regression procedures indicated that the predicted cumulative rate for these four illnesses increased by 406 hospitalizations per 100,000 per year for each PDR point. Taking the 10^{th} and 90^{th} percentiles of the observed PDR distribution as the boundaries for low and high physical demand occupations, the high demand job would have one more hospitalization per year for every 124 incumbents.

Conclusions

Occupational physical demands have very specific effects on health. These demands increase the rates of accidents, musculoskeletal disorders, inguinal hernia, and cellulitis. For these illnesses, the statistically significant correlations to PDRs can be interpreted reasonably as cause and effect. Alcohol-related illnesses were not included when estimating health effects because these associations may not be cause and effect. The specificity of the associations and the size of the hypothesized correlations provide further evidence that PDRs are valid indicators of occupational physical demands.

PDR-illness relationships yield useful estimates of the magnitude of health effects of occupational physical demands. The initial estimate provided here is only illustrative. This estimate can be refined in two ways. Additional work is needed to translate hospitalizations into different units of measurement. Expressing health effects as work days lost or in monetary terms would be useful. For example, if physical fitness reduces illness rates, the cost-benefit ratio of the physical conditioning required to achieve a given level of physical fitness can be computed by comparing the time required for conditioning to the reduction in time lost to illness. The health criterion also should be extended to include minor illnesses that are treated on an outpatient basis. These illnesses are relatively mild and typically will result in only a short period of time lost from work, but these illnesses are so frequent that the costs involved may equal or exceed hospitalization costs. The issue of whether adjustments are needed to allow for associations between occupational demands and other potential influences on health status (e.g., age, ethnicity, gender) also needs to be examined.

The results of this study provided a demonstration of the potential for estimating the health costs of occupational physical demands and set the stage for efficient refinements of the initial estimate. The scope of the estimation problem has been reduced from the consideration of as many as 28 illness rates (if individual subcategories all had to be considered) to the study of four illness rates. Detailed investigation of four rates can now be undertaken with reasonable confidence that important health consequences of occupational physical demands are not being omitted.

Introduction

Military physical fitness programs address concerns for the health and operational readiness of military personnel (Department of Defense, 1995; Chief of Naval Operations, 1990). Different occupational demands may make it appropriate to set different fitness standards for different occupations (Department of Defense, 1995).[1] What health effects would be expected if physical fitness standards were raised for selected occupations? Building on Carter & Biersner (1987) and Vickers, Hervig, and White (1997), this study explores this question using physical demand ratings (PDRs) to estimate the health effects of occupational physical demands.

Vickers et al. (1997) demonstrated that PDRs predict health outcomes in U.S. Navy entry-level jobs. That study was focused on establishing the validity of PDRs as indicators of occupational physical demands. This focus led to the adoption of back injury hospitalization rates as the health criterion. This criterion provided the necessary linkage to theoretical models that provided the conceptual basis for determining whether the ratings could be interpreted as indicators of exertion on the job. In particular, biomechanical models predict that back injuries can be the result of overexertion in physical tasks (Waters, Putz-Anderson, Garg, & Fine, 1993). The study findings were clear: PDRs strongly predicted back injury rates.

Vickers et al. (1997) provided other evidence that helped rule out alternative interpretations of PDRs. Other job demands (e.g., reasoning) did not predict back injury rates. PDRs did not predict the overall rate of hospitalization for all causes. These observations eliminate explanations that imply that PDRs are merely one indicator of a generally demanding job (e.g., halo effects in ratings). These observations also eliminated interpretations that assume that back injury rates were just one indicator of a general tendency to seek and receive health care (e.g., hypochondriasis, malingering). The overall pattern of convergent and discriminant validity coefficients was consistent with what would be expected if PDRs assessed the occupational requirements for physical exertion.

The Vickers et al. (1997) findings helped fill out a picture of PDRs as valid indicators of occupational exertion. Carter and Biersner (1987) had demonstrated previously that PDRs strongly discriminate between high physical exertion jobs and other jobs when exertion level was determined by direct measurements and observation. The addition of the Vickers et al. (1997) results meant PDRs were related to both the occupational conditions that should cause high ratings and the health consequences that are known to follow from those conditions. The inference was that PDRs were valid indicators of occupational requirements for physical exertion.

This study shifts the focus of investigation from establishing the validity of PDRs to using those valid measures to define the range of health effects of occupational physical exertions. The ultimate objective is to quantify the health effects of occupational physical demands. Once quantified, the estimates can be used to evaluate the potential gains from job redesign or physical training programs designed to reduce those demands or condition incumbents to meet them.

Three health criteria logically are consequences of physical exertion on the job. These criteria were hospitalization rates for accidents, musculoskeletal disorders, and inguinal hernia.[2] Illnesses in each of these diagnostic categories are plausible consequences of acute or chronic occupational exertion. For example, the cause listed for about 16% of all hospitalizations for accidents in the U.S. Navy is listed "Falls and miscellaneous, including twisting, turning, slipping, lifting, and hanging/suffocation (not self-inflicted)" (Ferguson, McNally, & Booth, 1981). Biomechanical models of accidental injury (Waters et al., 1993) and prior studies of musculoskeletal injuries in civilian populations (Chaffin, Herrin, & Keyserling, 1978) provide additional reason to believe that heavy occupational physical demands will increase the frequency of accidents and musculoskeletal disorders. Similarly, inguinal hernia can be a consequence of physical exertion, especially chronic exertion (Carbonell et al., 1993; Flic, Alfonso, Delgado, Prado, & Cortina, 1992; Smith, Crosby, & Lewis, 1996). Based on these general considerations, significant positive correlations were anticipated between PDRs and each of the focal health criteria.

Other occupational demands and other health criteria have been included in this study to provide the context necessary to interpret the hypothesized correlations mentioned in the preceding paragraph. Vickers et al.'s (1997) prior validation study of PDRs illustrated the importance of having a pattern of associations to interpret hypothesized correlations in this domain. If all other correlations between job demand ratings and health indices were known to be approximately equal to zero, a significant correlation between PDRs and the hypothesized health effects of occupational physical exertion would be a satisfactory test of the hypothesis. However, these other correlations probably are not equal to zero. Shaw and Riskind (1983) reported a diffuse pattern of associations between occupational attributes and health criteria with statistically significant results occurring with greater than chance frequency. Those authors interpreted their results as evidence that stress affects health. Stress is an abstract, general construct encompassing many different stimuli, so explanations based on stress are different than ones based on specific causal factors (Hinkle, 1973). Shaw and Riskind's (1983) findings raise the possibility that any PDR-illness relationships that might be observed in this study could be interpreted as nothing more than another manifestation of nonspecific effects of occupational stress. In the absence of evidence to refute this interpretation, an explanation based on the more general construct of stress would be preferred to an explanation based on the narrower construct of physical exertion. The stress interpretation could be refuted if the hypothesized correlations were large relative to the correlations between other job demands and health criteria.

The study objectives were restated as hypotheses linking the issues involved in quantifying the health effects of occupational physical demands to specific results presented in this report. The hypotheses were:

(A) PDRs will be positively related to hospitalization rates for accidents, musculoskeletal disease, and inguinal hernia.

(B) PDRs will predict their hypothesized correlates better than other occupational demands predict hospitalization rates.

The information obtained in testing these hypotheses then is used to estimate the health effects of occupational physical demands.

Methods

Navy Occupations

Fifty-seven (57) entry-level U.S. Navy occupations were studied. The specific occupations were chosen as follows:

A. The 75 entry-level occupations with occupational demand ratings in Reynolds, Barnes, Harris, & Harris' (1992) study were included.

B. The 18 three-letter occupational codes from Reynolds et al. (1992) were collapsed into 6 two-letter classifications. This reduction mapped their codes onto the two letter codes used for the health data in this study (Jaeger, White, & Show, 1996). For example, Aviation Structural Mechanics working with safety equipment (AME), hydraulics systems (AMH), and metal structures (AMS) were treated as a single category of Aviation Structural Mechanic (AM).[3]

C. Four occupations with fewer than 1000 person years of observation in the health database were dropped. The small sample size meant that estimates of hospitalization rates would be imprecise for these groups. Low precision of estimates is the statistical basis for unreliable measurement (American Psychological Association, 1985), and unreliable measures reduce the magnitude of observed correlations (Nunnally & Bernstein, 1994). Retaining those four occupations, therefore, would increase the probability of incorrectly accepting the null hypothesis. The 61 occupations retained for analysis at this point had hospitalization rates based on between 3,582 and 421,174 person years of observation.[4]

D. Hospital Corpsmen (HM) and Dental Technician (DT) occupations were dropped as statistical outliers. Vickers et al. (1997) dropped these occupations from their analyses because they were statistical outliers when regressing back injury hospitalization rates on PDRs. Outlier status arose because these occupations combined high back injury rates with moderate occupational physical demands. Gunderson and Colcord (1982) reported that these occupations have elevated hospitalization rates for many health problems. Their outlier status, therefore, was likely to generalize from back injury to other health problems. Multivariate analysis of the health criteria confirmed this speculation,[5] so these two occupations were dropped from the analysis.

Job Demand Ratings

Job demand ratings were taken from Reynolds et al.'s (1992) Job Activities Inventory, an instrument that included ratings of 27 different job-related abilities. Each ability was rated for its importance to job performance on a 5-point scale with "Not Very Important," "Somewhat Important,", "Important," "Very Important," and "Extremely Important" as response anchors. These responses were scored 1, 2, 3, 4, and 5, respectively. Respondents also were offered the choice of "Not Applicable" as a response. This response was treated as missing data and not used in the computation of occupational scores.

This study used the same 8 ability ratings used by Vickers, Hervig, and White (1997). Four of the eight ratings assessed the importance of physical abilities:

Strength: Ability to use muscle force in order to lift, push, pull, or carry heavy objectives for a short period of time.

Flexibility: Ability to bend, stretch, twist, or reach out with the body, arms, or legs.

Body Balance: Ability to keep or regain one's balance or to stay upright when in an unstable position.

Stamina: Ability to exert oneself physically without getting out of breath.

The total physical demands of the occupation were measured by averaging the Strength, Flexibility, Body Balance, and Stamina scores for each occupation. The summary measure was computed because ratings of specific physical ability requirements were very highly correlated and defined a single dimension in Reynolds et al.'s (1992) factor analysis of the full set of 27 ratings.

Four other ability ratings were chosen to represent the cognitive and psychomotor ability domains identified in Reynolds et al.'s (1992) factor analysis of the importance ratings. The following items were chosen to represent "Communication," "Cognitive Ability," "Perceptual Skill," and "Dexterity and Fine Motor Control," respectively:

Oral Communication: Ability to use English words and sentences so others will understand and the ability to understand the speech of others.

Reasoning: Ability to understand and organize a problem and then to select a method for solving the problem.

Reaction Time: Ability to give a fast response to a signal (sound, light, picture) when it appears.

Dexterity: Ability to quickly make skillful, coordinated movements of the fingers, hands, wrists, arms, or legs.

Each item was the one that had the highest loading on the factor it was chosen to represent.

Hospitalization Rate Variables

Forty-one (41) hospitalization rates (Table 1) were computed using the Epidemiological Interactive System (EPISYS) developed at the Naval Health Research Center (Jaeger et al., 1996). The system can generate hospitalization rates for all ICD-9 diagnoses (Medicode, Inc., 1991) for the total U.S. Navy population and for subgroups within that population. In the present application, rates were generated separately for all U.S.

Table 1. Hospitalization Rate Variables

Illness	Rate
Infectious Diseases (001-139)	604.28
Neoplasms (140-239)	176.32
Endocrine, Nutritional, and Metabolic Diseases and Immune Disorders (240-279)	129.89
Diseases of Blood/Blood Forming Organs (280-289)	110.60
Mental Disorders (290-319)	1289.47
Psychotic Disorders (290-299)	142.53
Neurotic Disorders (300)	118.24
Personality Disorders (301)	381.98
Alcohol Intoxication (303)	558.38
Alcohol Abuse (305)	234.90
Depression/Situational Reaction (309)	251.12
Diseases of the Nervous System/Sense Organs (320-389)	263.53
Disease of Circulatory System (390-459)	267.04
Diseases of Respiratory System (460-519)	569.64
Diseases of Digestive System (520-579)	845.68
Inguinal Hernia (550)	204.18
Noninguinal Digestive (All except 550)	641.50
Diseases of Genitourinary System (580-629)	447.38
Diseases of Skin/Subcutaneous Tissue (680-709)	352.92
Cellulitis (681,682)	157.61
Noncellulitis (All others except 681, 682)	195.31
Diseases of Musculoskeletal System and Connective Tissue (710-739)	851.81
Arthropathies and Related Diseases (710-716)	73.27
Internal Derangement of Knee (717)	209.32
Internal and Other Derangements of Joints (718,719)	199.76
Disorders of Discs/Spinal Stenosis (722-724)	181.88
Rheumatism, excluding back (725-729)	244.60
Osteopathies/Chondropathies/Acquired Musculoskeletal Deformities (730-739)	250.50
Injuries and Poisoning (800-999)	1384.79
Fracture, Skull (800-804)	95.02
Fracture, Neck or Trunk (805-809)	64.34
Fracture, Upper Limb (810-819)	167.42
Fracture, Lower Limb (820-829)	205.20
Dislocation (830-839)	147.04
Sprain (840-848)	221.29
Intracranial Injury (850-854)	126.16
Internal Injury (860-861/9?)	50.79
Wound, Head/Neck/Trunk (870-879)	109.86
Wound, Upper Limb (880-887)	109.88
Wound, Lower Limb (890-897)	45.45
Late Effects of Injury, Poisonings, Toxics, and Other External Causes (905)	61.06

Note. ICD-9 codes included in the criterion given in parentheses. Rates are hospitalizations per 100,000 person years of observation.

Navy ratings covered by EPISYS. The rates for the 59 occupations of interest then were extracted and matched to the occupational demand ratings.

The 41 hospitalization rates computed included 13 rates for major disease and illness categories defined in EPISYS (Jaeger et al., 1996).[6] The remaining 28 rates represented diagnostic subcategories within the major categories. Most subcategories consisted of diagnosis groups defined in the ICD-9 manual (e.g., Osteopathies/Chondropathies/Acquired Musculoskeletal Deformities). Individual three-digit ICD-9 codes were singled out (e.g., Internal Derangement of Knee, ICD-9 code 717) when the hospitalization rate for the diagnosis exceeded 100 hospitalizations per 100,000 person-years of observation. Diagnostic groups with lower rates were singled out only if the subcategory was in the accident or musculoskeletal disorder domains.

To simplify the presentation of results for the remainder of this paper, individual hospitalization rates are simply referred to as "rates." Unless specifically mentioned, the qualifiers "hospitalization" and "per 100,000 person-years of observation" should be added to all rate references.

Four general ICD-9 categories were excluded from this study. The first category consisted of illnesses of pregnancy and childbirth (Complications of Pregnancy, Childbirth, Perpeurium, ICD-9 codes 630-676; Conditions Originating in Perinatal Period, ICD-9 codes 760-779). These health problems apply only to the women who comprise 10% to 15% of the total U.S. Navy population. In many Navy occupations, the proportion of women would be much smaller. The person years of observation, therefore, would fall below any reasonable minimum criterion based on precision of estimation of health outcomes in many occupations. Congenital problems (ICD-9 codes 740-759) were excluded because, by definition, they could not be the result of exposure to occupational demands. Symptoms/Signs and Ill-Defined Condition (ICD-9 codes 780-799) were excluded because these diagnoses, by definition, did not reflect specific, identifiable health problems.

The correlations relating PDRs to illnesses were divided into focal correlations and other correlations. The hypothesis that accident rates, musculoskeletal disease rates and inguinal hernia rates would be related to occupational physical demands identified three correlations that should be statistically significant. Applying the hypotheses about overall categories to specific illness rates within the categories, the hypothesis also implied that PDRs would predict subcategory diagnoses for accidents and musculoskeletal disease. Also, inguinal hernia represents a substantial portion of the overall digestive system disease burden for U.S. Navy enlisted personnel (Table 1). If PDRs predict the rates for inguinal hernia as hypothesized, generalizing from the part to the whole makes it reasonable to expect that PDRs will predict the rates for the general category of digestive system disease. With these points taken into account, the study hypotheses implied that PDRs would be related to 22 of the 41 rates. The correlations between PDRs and these 22 rates were the primary foci of the study hypotheses and were so labeled to distinguish them from other associations that lacked a hypothetical relationship to PDRs.

Analysis Procedures

Correlation and regression analyses were performed with the SPSS-X statistical package (SPSS, Inc., 1992). The significance criterion for bivariate correlations between occupational demands and illness rates was set at $p < .05$, two-tailed.[7]

As discussed in the Introduction, the hypothesized correlations were evaluated in the context provided by other associations in the study. Context was quantified in two ways:

A. The proportion of significant correlations for other occupational demands was determined.

B. The average absolute value of the correlations for other occupational demands was computed.

The overall degree of association between occupational physical demands and the hypothesized illness correlates was evaluated by comparing the proportion of significant associations to the proportion of significant correlations for other job demands (see (A) above). The significance of individual correlations between occupational physical demands and rates was determined by comparing them to the typical correlation between other occupational demands and rates ($r = .237$; see Results for details). A correlation of $r \geq .433$ was statistically significant.[8]

Results

Context Correlations

A diffuse pattern of statistically significant associations relating reaction time, dexterity, communication, and reasoning occupational demands to rates was evident in the data. Forty-five percent (74 of 164) of the correlations were statistically significant ($p < .05$, two-tailed). Despite this high rate of significant associations, the average correlation in Table 2 was only $r = .023$. The small average value was explained by the fact that large positive correlations for one occupational demand (e.g., reaction time) were offset by large negative correlations for another occupational demand (e.g., reasoning).

The mean absolute value of the correlations ($r = .237$) provided a useful quantitative measure of the typical strength of association. This value was representative in several ways. The mean absolute value for each individual occupational demand was close to this figure (Communication, $r_{abs} = .210$; Reasoning, $r_{abs} = .238$; Reaction Time, $r_{abs} = .240$; Dexterity, $r_{abs} = .253$). The two largest means for the signed correlations also were close to this value (Reasoning, $r = -.235$; Dexterity, $r = .253$).

Physical Demands and Hospitalization Rates

The focal correlations (see *Hospitalization Rate Variables* section of Methods for definition of focal and other correlations) supported the study hypothesis (Table 3). All 22 correlations were positive. Thus, higher occupational physical demands were uniformly associated with

Table 2. Correlations of Other Occupational Demands with Hospitalization Rates

Illness Category	Communication	Reasoning	Reaction Time	Dexterity
Infections	.529	-.144	-.033	.153
Neoplasms	.300*	.056	-.399*	.232
Blood & Blood Forming Organs	.285*	-.100	-.361*	.187
Metabolic & Immune Disorders	.172	-.158	-.372*	.161
Mental	.026	-.439*	.152	.354*
Alcohol Abuse	-.150	-.356*	.279*	.377*
Alcohol Intoxication	-.194	-.405*	.158	.273*
Neurotic	.377*	-.330*	.035	.005
Psychotic	.184	-.297*	-.182	.292*
Personality	.212	-.310*	.102	.345*
Depression	.348*	-.229	.184	.286*
Nervous System	-.097	-.348*	-.135	.360*
Circulatory	.052	-.301*	-.155	.110
Respiratory	.009	-.157	-.026	.294*
Digestive System	.061	-.297*	-.025	.397*
Inguinal Hernia	-.246	-.181	.181	.255
Noninguinal Digestive	.195	-.268*	-.119	.352*
Genitourinary	.275*	-.142	-.493*	.042
Skin	-.160	-.343*	.246	.337*
Cellulitis	-.121	-.283*	.305*	.233
Noncellulitis Skin	-.124	-.242	.071	.283*
Musculoskeletal	-.263*	-.281*	.138	.347*
Arthropathy	-.024	-.176	.000	.203
Knee	-.235	-.192	.404*	.209
Other Joints	-.294*	-.312*	.247	.260
Discs/Spine	-.068	-.170	.095	.312*
Rheumatism	-.322*	-.212	-.182	.228
Osteopathy	-.284*	-.260	.144	.409*
Injuries and Poisoning	-.232	-.304*	.430*	.298*
Skull Fracture	-.232	-.218	.418*	.126
Neck Fracture	-.287*	-.132	.376*	.240
Upper Limb Fracture	-.343*	-.140	.356*	.237
Lower Limb Fracture	-.240	-.188	.495*	.314*
Dislocation	-.299*	-.263*	.304*	.091
Late Effects	-.408*	-.201	.201	.310*
Intracranial Injury	-.036	-.183	.282*	.169
Internal Injury	-.232	-.076	.291*	.145
Head/Neck/Trunk Wound	-.220	-.256*	.217	.273*
Upper Limb Wound	-.281*	-.208	.295*	.295*
Lower Limb Wound	-.174	-.324*	.455*	.269*
Sprain	-.018	-.266*	.506*	.297*

Note. *$p < .05$ ($\rho = .00$). See text for details. See Table 1 for full names and ICD-9 codes of disease variables.

higher rates as predicted.

The distribution of the focal correlations was skewed toward large positive associations. The skew was evident even in the context of the correlations in Table 2. Ninety-five percent (21 of 22) of the focal correlations were statistically significantly greater than zero. This proportion of significant associations was much higher than expected by chance if the focal correlations had come from the same population of correlations that generated the 45% significance rate in Table 2 (χ^2 = 22.63, 1 df, p < .001).

The individual focal correlations also were large. The average focal correlation was nearly twice as large as the typical correlation in Table 2 (r = .473 vs. r = .237). This trend resulted in 64% (14 of 22) of the focal correlations being significantly ($p < .05$, one-tailed) greater than ρ = .237.

Associations between PDRs and the 19 illness rates that were not covered by the initial study hypotheses were comparable to those in Table 2, except in one respect. The frequency of statistically significant associations was approximately the same (41% vs. 45%; χ^2 = .06, p > .800). The average absolute value of these other PDR correlations (r = .263) was slightly higher than the average absolute value in Table 2 (r = .237). However, the correlations between PDRs and these other 19 illness rates included a higher than expected frequency of large (i.e., r > .435) correlations compared to Table 2 (5 of 19 vs. 6 of 164).

Consistency of Associations in Major Disease Categories

The correlations between PDRs and illness rates varied substantially when subcategories of diagnosis within the accident and musculoskeletal domains were considered. The range of correlations was approximately 0.400 in each case (accidents, r = .312 to r = .719; musculoskeletal disorders, r = .166 to r = .554). This range appears to be wide as it represents 20% of the maximum possible range (i.e., 2.00 if one correlation were $r = -1.00$ and another were $r = 1.00$). Despite this appearance, application of Hays' (1963, p. 532) *V* test for the variability of a set of correlations indicated that the observed variability was no greater than expected by chance (accidents, χ^2 = 16.23, 11 df, p < .133; musculoskeletal disease, χ^2 = 7.67, 5 df, p < .175).

Examination of the individual correlations within the accident and musculoskeletal disorders categories in Table 3 indicated that overall variability might not be the appropriate way to describe the correlations within each category. The correlations in each category appeared to include an outlier that increased the apparent scatter of the correlations. In the case of musculoskeletal disorders, the Arthritis correlation was significantly smaller than average (r = .166 vs. r = .486, z = -2.72, p < .004). In contrast, the Arm Wound correlation was significantly larger than average for accidents (r = .719 vs. r = .446, z = 3.19, p < .0008). Both results were statistically significant even with a Bonferroni adjustment (cf., Harris, 1985, pp. 7-9) to allow for the number of significance tests performed.

Table 3. Correlations of Occupational Physical Demand Ratings (PDRs) with Hospitalization Rates

Illness Category	Physical Demands
Hypothesized Correlates	
Musculoskeletal Disorders	.594*#
Arthropathy	.166
Knee	.536*#
Other Joints	.457*#
Discs/Spine	.554*#
Rheumatism	.475*#
Osteopathy	.397*
Injuries and Poisoning	.627*#
Skull Fracture	.574*#
Neck Fracture	.472*#
Upper Limb Fracture	.522*#
Lower Limb Fracture	.431*
Dislocation	.526*#
Late Effects	.450*#
Intracranial Injury	.404*
Internal Injury	.316*
Head/Neck/Trunk Wound	.507*#
Upper Limb Wound	.719*#
Lower Limb Wound	.312*
Sprain	.346*
Digestive System	.422*
Inguinal	.594*#
Noninguinal Digestive✻	.214
Other Hospitalization Rates	
Infections	.008
Neoplasms	-.275*
Blood & Blood Forming Organs	-.173
Metabolic and Immune Disorders	.059
Mental	.504*
Alcohol Abuse	.496*
Alcohol Intoxication	.643*
Neurotic	-.039
Psychotic	.226
Personality	.106
Depression	.091
Nervous System	.315*
Circulatory	.394*
Respiratory	.243
Genitourinary	-.232
Skin	.551*
Cellulitis	.600*
Noncellulitis Skin	.244

✻Not a hypothesized correlate of occupational physical demands; placed here for easy comparison to inguinal hernia.

Note. $^*p < .05$ ($\rho = .00$); $^\#p < .05$ ($\rho = .237$). See text for details. See Table 1 for full names and ICD-9 codes of disease variables.

Table 4. Estimated Effects of Occupational Physical Demands on Illness

	Type of Regression: Uni-variate	Multi-variate	Difference
Individual Criteria			
Accidents	261.15	238.91	9.3%
Musculoskeletal Disorders	117.82	108.54	8.5%
Inguinal Hernia	30.93	30.93	0.0%
Cellulitis	29.31	27.13	8.0%
Sum of Weights from Individual Criteria	439.21	405.51	8.3%
Weight from Cumulative Illness Criterion	439.21	406.48	8.1%

Note: Table entries are regression weights for PDRs. See text for details. The full regression equations for the individual criteria are given in Appendix A.

Curvilinearity

Vickers et al. (1997) found that a quadratic function described the relationship between occupational physical demands and back injury rates better than a linear function.[7] Polynomial regressions were performed to test for similar trends in the present data. A quadratic term was significant if it accounted for 5.9% or more of the variance in the dependent variable. This criterion equaled the amount of variance required for a significant ($p < .05$, two-tailed) linear relationship in the initial analysis stage (i.e., $r \geq .242$, $r^2 \geq .059$).

Linear models adequately summarized the associations between occupational demands and rates.[9] The quadratic term met the criterion in only 17 of 450 analyses (binomial $p_{.05,450} < .908$). Only 1 of 22 focal relationships met the criterion (binomial $p_{.05,22} < .676$).

Cumulative Effects of Physical Demands

Four estimates of the cumulative health effects of occupational physical demands were derived. The computations were limited to four illnesses that were both logically and empirically related to occupational physical exertion (musculoskeletal diseases, accident rates, inguinal hernia rates, and cellulitis; the Discussion section of this report gives the rationale for including cellulitis). First, each of those four rates was regressed individually on PDRs. The four resulting PDR regression weights were summed to estimate cumulative effects. Second, the four rates were summed, then the sum was regressed on PDRs. The single PDR regression weight from that equation was the second cumulative effect estimate.

Multivariate predictive models provided two more estimates of cumulative health effects. Stepwise regressions were performed with the five occupational demand measures as the possible predictors. A $p < .05$ criterion was used to determine which predictors entered the equation. The stepwise procedure was applied first to the four individual rates, then to the sum of those rates. The third cumulative effect estimate was the sum of the multivariate PDR regression weights for the four individual rates. The fourth estimate was the multivariate PDR regression weight from the equation for the sum of the individual rates.

Overlap between the predictor variables affected the size of the estimated health effects of occupational physical demands, but criterion aggregation did not (Table 4). Health effect estimates from univariate regressions were 8.3% larger than the estimates from multivariate regressions. In contrast, virtually identical results were obtained by summing regression weights across individual illness criteria or by computing a single regression weight for a summed criterion.

Discussion

Higher occupational physical demands were associated with higher rates for accidents, musculoskeletal disease, and inguinal hernia as predicted. The predicted associations were strong even in the context of a general tendency for different occupational demands to predict a wide range of rates. These three illnesses define a minimum set of health consequences that must be considered when estimating the health effects of performing a physically demanding occupation.

Higher cellulitis rates are a fourth consequence of performing a physically demanding occupation. The possibility that cellulitis is a consequence of performing a physically demanding job was suggested by a strong correlation between PDRs and cellulitis rates. The definition of cellulitis suggests that this association may indicate a cause-effect relationship. Cellulitis is ". . . an acute diffuse, spreading, edematous, suppurative inflammation of the deep subcutaneous tissues and sometimes muscle . . . usually caused by infection of an operative or traumatic wound, burn, or other cutaneous lesion by various bacteria . . . " (Saunders, 1994). If physical demands cause accidents, as it appears reasonable to believe, a physically demanding job can produce the wounds, burns, or other lesions that set the stage for cellulitis. Combining the empirical association with the definition of cellulitis, occupational physical demands are logically an indirect causal antecedent of cellulitis.[10]

Occupational physical demands have substantial health effects. Combining the rates for accidents, musculoskeletal disorders, inguinal hernia, and cellulitis, one point on the PDR scale means an estimated 4.1 to 4.4 additional hospital admissions per year for each 1,000 people. This value may appear modest, but it is substantial when placed in its proper context. The least physically demanding U.S. Navy occupation in this study (PDR = 1.60) had a predicted rate of 18.6 hospital admissions per 1,000 incumbents per year. The predicted rate increases 24% relative to this baseline value for each one point that the PDR increases. As a result, the predicted rate for the most physically demanding occupation (PDR = 4.08, predicted rate = 29.5) is 59% higher than that for the least demanding (PDR = 1.60, predicted rate = 18.6).

The magnitude of the health effects of occupational physical demands also can be illustrated by comparing low and high demand jobs. The 10^{th} percentile of the distribution of PDR scores is a reasonable definition of a low demand job. The 90^{th} percentile of the distribution is a reasonable definition of a high demand job. Given these definitions, high demand jobs receive a rating that is at least 1.99 points higher than that of a low demand job. If one rating point means 406 additional hospitalizations per 100,000 incumbents per year (per Table 4), the rating difference translates into a predicted difference of 808 hospitalizations per 100,000 incumbents per year. This figure amounts to 1 additional hospitalization for every 124 occupational incumbents.

The preceding computations may underestimate the health effects of occupational physical demands. Alcohol-related diseases were excluded from the estimates. A case for including these diseases could be made on the basis of their strong empirical relationships to PDRs. However, it is doubtful that those relationships should be interpreted as evidence that occupational exertion actually causes alcohol consumption. It might be argued that people consume alcohol to relax from the rigors of their work after a demanding day. However, hard work and alcohol consumption also could be linked by social dynamics that foster a "Work hard, play hard" attitude. Another possibility is that people who enter physically demanding occupations tend to have higher than average risk taking and/or sensation-seeking personality tendencies. Heavy alcohol consumption might be one expression of those attributes. Until these possibilities are examined, excluding alcohol-related diseases provides a conservative estimate of the health effects of occupational physical demands.

The results obtained in this study imply a simple solution to the problem of modeling the health effects of occupational physical demands. A single equation relating demands to the sum of the rates for accidents, musculoskeletal diseases, inguinal hernia, and cellulitis may provide an adequate model. This model would be substantially simpler than one that considered each illness criterion separately. The simpler model is parsimonious in that it requires fewer parameters than a model based on individual health criteria (Popper, 1959). The simpler model also can be justified on both conceptual and practical grounds. Conceptually, occupational physical demands arguably are a cause of each of the four illnesses summed to produce the single criterion. As a result, the sum of the four rates can be interpreted as an emergent scale measuring the magnitude of those demands (Bollen & Lennox, 1989). Pragmatically, the estimated effect of occupational physical demands on health was approximately the same whether the four diseases were analyzed individually or as a composite (cf., Table 4). Given this equivalence, there is no obvious reason why a more complex model should be constructed.

The differences in correlations within the study support the claim that the nominal effects of exposure to occupational physical demands reflect real causal relationships. The difference between the size of the initially hypothesized correlations compared to the general context provided by the correlations between illness rates and other occupational demands is one part of the basis for this claim. The specificity of associations within general ICD-9 categories is another basis for this claim. PDRs were much more strongly related to the inguinal hernia rate ($r = .594$) than to the rate for other digestive diseases ($r = .214$). Similarly, the relationship between occupational physical demands and cellulitis rate ($r = .600$) was much stronger than the relationship between those demands and other types of skin disease ($r = .244$). These results strengthen the basis for claiming that PDRs are valid indicators of the physical exertion required by the occupation and that on-the-job physical exertion is a cause of occupational differences in selected illnesses.

Job demand ratings for reaction time, dexterity, communication, and reasoning were included in this study to provide context for the PDR findings. The results obtained with these measures not only served the intended purpose, but also produced several findings that were interesting in their own right. Two of these incidental findings that may be important for understanding illness patterns in the U.S. Navy were especially noteworthy. First, 11 of 13 accident rates were related to reaction time ratings. While these findings suggest that personnel in some U. S. Navy enlisted occupations can be divided into the quick and the injured, the suggestion is misleading. The reaction time ratings represent a general perceptual skill factor identified by Reynolds et al. (1992). The factor also included ratings of the needs for sensitivity to visual and auditory signals in the work environment and for rapid interpretation of the significance of the cues.[11] Considering the full set of correlated ratings, the reaction time demands can be interpreted as indicating a need for situational awareness. The empirical associations between these demands and accident rates imply that subjective hazard ratings are useful estimates of actual hazard levels.

The second noteworthy incidental finding provides another reminder that correlations between occupational demands and illnesses should not be interpreted reflexively as indicating cause-effect relationships. Higher occupational demands for reasoning were associated with lower mental disease rates. If these associations were treated as cause and effect, the relationships could be interpreted as indicating that performing mentally demanding tasks on the job reduces the likelihood of mental health problems. However, evidence from other research indicates that people with above average mental ability have somewhat lower than average scores on measures of anxiety, aggressiveness, and inability to deal with stress (Ackerman & Heggestad, 1997). If people with above average mental ability are selected for occupations that require reasoning, the result will be that people in those occupations have below average risk of mental health problems. The selection effect will be weak because the associations between mental ability, the actual selection variable, and attributes that affect the risk of mental illness are weak. However, even weak selection effects at the level of individuals can produce strong group differences (e.g., Martell, Lane, & Emmrich, 1996).[12]

Several limitations of this study should be kept in mind when interpreting the findings. The conclusions are based on reasoning about the causes of individual accidents, but the actual results reported here are ecological correlations (i.e., correlations between attributes measured for groups, not individuals). The causal processes that produce individual differences are not necessarily the same ones that produce group differences (Rose, 1975). Previous studies (Chaffin, Herring, & Keyserling, 1978) provide reason to believe the view that the ecological correlations arise because more individuals encounter specific conditions that cause individual accidents in high-risk occupations than in low-risk occupations.

The timing of the measurement of occupational demands also is a factor to consider. Occupational demands were assessed near the end of the period of aggregation for the health data. In effect, the presumed cause was measured after the presumed effects had been observed. Perhaps observations of injuries on the job were one factor that determined the ratings of physical demands. This reversal of the putative cause-effect relationship may be reasonable, but the relative timing of the PDR and illness measurements should not be given too much weight. The PDR scores probably represent conditions that existed throughout the period during which the health data were accumulated. Carter and Biersner (1982) analyzed Position Analysis Questionnaire (PAQ; Mecham, McCormick & Jeanneret, 1977) data for 80 U.S. Navy occupations. Those data, gathered in 1972, indicated that the Boiler Technician, Gunner's Mate, Hull Technician, and Machinist's Mate occupations were in the top 10% of stamina scores compared to civilian occupations. Data Processor and Radioman occupations were in the bottom 10%. These occupations were not as extreme on three other physical demand ratings included in the study, but actual percentiles were not reported. Based on Reynolds et al.'s (1992) factor analysis findings, it can be suggested that the other physical demand ratings probably were strongly positively correlated with stamina. If so, the PAQ data was very similar to Reynolds et al.'s (1992) findings. The 1992 data placed the first four occupations in the top third of the PDR distribution; the other two occupations were in the bottom third. Based on this evidence, the occupational differences in physical demands that were related to illness antedated the initial health criteria and persisted throughout the 1980-1994 period. The aggregate health trend is a suitable basis for evaluating the impact of these chronic differences in exposure to risk.

The lack of controls for demographic correlates of illness is another limitation of this study. Age, general intelligence, gender, and pay grade are related to illness rates (Doll, Rubin, & Gunderson, 1969; Gunderson, Rahe & Arthur, 1970; Rubin, Gunderson, & Arthur, 1971; Hoiberg, 1981; Ferguson, McNally & Booth, 1983, 1985; Helmkamp & Colcord, 1984; Nice & Hilton, 1990; Palinkas & Colcord, 1983; Bone & Helmkamp, 1986; Helmkamp & Bone, 1986). If these attributes differ between occupations, as seems likely (e.g., general intelligence test scores are one basis for selection into some occupations), the failure to adjust for the differences may bias the estimates of the health consequences of exposure to occupational physical demands. This study did not adjust for demographic variables because the issue of whether such adjustments are appropriate is complex.[13] Future studies should address this topic to ensure that estimates of the health effects of physical demands are not biased. The present study is a valuable step toward this end because it identified a subset of illnesses as the key variables to be examined in greater detail.

Finally, the fact that hospitalization rates were the only illness criterion in this study is a significant limitation. Outpatient treatment rates are roughly 20 to 40 times as high as hospitalization rates for U.S. Navy enlisted personnel.[14] Although outpatient treatment involves only mild illnesses, the cumulative health effects can be important because of their high frequency. For example, about 10% of accidental injury cases aboard an aircraft carrier resulted in one or more days of "no duty" or "light duty" restrictions (Krentz, Li, & Baker, 1997). Accident rates for males aboard destroyer tenders, submarine tenders, repair ships, salvage ships, and oilers averaged 98.5 per 1000 per month (Nice & Hilton, 1990). This figure translates to 118,200 accidental injuries per 100,000 per year. If 10% of these injuries result in time lost from full duty status, injuries alone account for 11,820 cases of time lost per 100,000 sailors per year. This figure is greater than the rate of hospitalizations for all causes (8,800 per 100,000 per year). Even though the time lost from duty is relatively brief when patients are treated on an outpatient basis, omitting outpatient illness clearly will underestimate the health effects of performing a physically demanding occupation.

The primary conclusions from the present study can be summarized briefly. First, occupational physical demands increase the rates for accidents, musculoskeletal disease, inguinal hernia and cellulitis. Second, the rates for the general ICD-9 categories for injuries and poisoning and musculoskeletal disease represent the appropriate level of aggregation for modeling the effects of occupational physical demands on these illnesses. Third, occupational physical demands produce health effects that amount to 4.1 hospitalizations per 1,000 personnel every year for each PDR point. Further study is needed to determine whether estimates of the health effects should be adjusted for demographic attributes and to add outpatient treatment to the criterion. The precise estimate of the impact of occupational physical demands on health may vary substantially depending on how these considerations are treated. The present study provides a useful initial estimate of the health effects of occupational physical demands and identifies the illnesses that should be the focus of efforts to refine that estimate.

Footnotes

[1]The term "occupation" is used in this paper rather than the U.S. Navy term "rating." The term "rating" is used in this paper to refer to subjective judgments of occupational demands.

[2]The full nomenclature for accidents in previous research on U.S. Navy personnel has been "accidents, poisonings, and violence." However, for U.S. Navy personnel, it appears that nearly all hospitalizations in this category are the result of accidents rather than combat injury, violence, or self-inflicted wounds. Ferguson, McNally, and Booth (1985) dropped accident, poisonings, and violence diagnoses arising from these causes in their study of accidents occurring in a cohort followed from 1974 through 1978. The reported accident rates for that study were only slightly lower than those observed in the present study. Also, it seems reasonable to expect the accident component of the overall rate to be the primary basis for any correlations to occupational demands. Therefore, this illness category referred to simply as "accidents" in the discussion of hypotheses and study findings in this paper. The formal category designation "Injuries and Poisoning" is used in the tables of results to correspond to the category label in ICD-9.

[3]The recoding process included the following: Aviation Boatswain's Mate for aircraft carrier (ABE), for fuel (ABF), and for aircraft and other equipment (ABH) to AB; Aviation Structural Mechanic for safety equipment (AME), hydraulics systems (AMH) and metal structures (AMS) to AM; Cryptologic Technician, administrative (CTA), interpretive (CTI), maintenance (CTM), operator (CTO), collection (CTC), and technical (CTT) to CT; Gas Turbine Systems Technician electrical/electronic (GSE) and mechanical (GSM) to GS; Ocean Systems Technician, Analyst (OTA) and Maintainer (OTM) to OT; and Sonar Technician, surface (STS) and Submarine (STM) to ST.

[4]The decision to restrict the analyses to occupations with more than 1,000 person-years of observation represented a trade-off between the desire to include as many occupations as possible and the desire to include only occupations for which hospitalization rates could be computed with acceptable precision. Precise estimates require extensive observations, so the two criteria had to be balanced against each other. The choice of 1,000 person-years of observation as the cutoff was based on two considerations. First, there was a substantial break in the frequency distribution for person-years of observation from 782 to 3,582. The precision of estimates at the lower end of this range would be substantially smaller than that at the higher end. Second, setting the criterion higher would have little effect on the study findings. Exploratory analyses for those occupations with 10,000 or more person-years of observations produced correlations very similar to those presented in the paper. The chosen criterion, therefore, produced results similar to those that would be obtained with more extreme criteria, but provided broader coverage of U.S. Navy entry-level enlisted occupations.

[5]The Hospital Corpsman (HM) and Dental Technician (DT) occupations were distant from all other data points. Expressed as Mahalanobis distances, the values were 44.92 for HM and 41.15 for DT. Well-defined guidelines for determining precisely what constitutes an outlier data point have not been agreed on by statisticians (Barnett & Lewis, 1978), but these two occupations would satisfy at least two commonly used tests for the

presence of outliers. First, these two data points were labeled outliers in a standard SPSS boxplot. Second, the gap between these two occupations and the next closest occupation (Opticalman [OM] = 30.87) was large relative to the scatter of the Mahalanobis distances (SD = 8.67). The difference of 10.28 amounted to 1.19 standard deviations. The range covered by moving down 1.19 standard deviations from Opticalman (OM) encompassed five occupations. No gap between the occupations in that range was larger than 0.54 standard deviations. Applying another approach, 2p/n defines a critical value for the hat matrix approach to identifying outliers (Belsley, Kuh, & Welsch, 1980). The critical value is 0.44 for the present data. This test can be applied to the Mahalnobis distances by noting that hat matrix values (h_{ii}) are approximately equal to the Mahlanobis distance divided by (n - 1), where n is the number of cases (Stevens, 1984). In the present case, this approximation yields h_{ii} values of 0.74 and 0.69 for the two outliers. The third largest h_{ii} was 0.51. While the h_{ii} criterion would exclude the two occupations (OM and LI) with Mahalanobis distances over 30.00, the fact that these distances were not outliers in the boxplot and were relatively close to several other data points was sufficient to retain them for the analysis. The fact that only a few sailors are members of the two marginal occupations at any one time also must be considered. Each of these occupations was represented by fewer than 7,000 person-years of observations in the database. The HM and DT occupations are much larger and have a correspondingly larger database for estimating rates (>260,000 and >32,000 person-years, respectively). The smaller sample sizes for the two marginal outliers means that the rates estimated for those occupations have larger margins of error. With this point in mind, the marginal outlier status of the OM and LI occupations had a higher probability of being the result of chance compared to the results for the HM and DT occupations. Overall, the HM and DT occupations were substantially further from the sample centroid (1.19 SD) than other possible outlier occupations, were located above a clear break in the distribution of the Mahalanobis distances, and passed two different tests for outlier status.

[6]Table 1 directs attention to an important point about the hospitalization rates. The sum of the subcategory rates within a category can be greater than the category rate. For example, the rate for Diseases of the Musculoskeletal System and Connective Tissue was 851.81. The sum of the rates for the six subcategories within this larger category was 1159.33. The difference between the rates arises because hospitalizations sometimes involve multiple diagnoses. When multiple diagnoses are present, EPISYS applies an "if any" strategy to code the admission. The hospitalization is counted as a case for a general category if at least one diagnosis in that category appears on the discharge record. If more than one diagnosis in that category appears on the discharge record, the hospitalization still only counts as a single case. When considering subcategories, multiple diagnoses can contribute to rates in more than one of the subcategories. For example, suppose a sailor had broken an arm and a leg in an accident. The two injuries would count as a single hospitalization when analyzed at the level of the general accidents, poisoning, and violence category of illness. When analyzed at the subcategory level, the broken arm and broken leg would be counted separately because they were in different categories. The single admission would yield an increment of one case for the overall Injuries and Poisoning category, but would add two cases to the sum of the rates for the Injuries and Poisoning subcategories. Scoring the single admission twice is necessary to get meaningful measures of the rates for subcategories.

[7]This criterion was conservative when applied to the PDR-rate relationships specified in the study hypotheses. Those hypotheses predicted that certain rates would be higher in occupations with high physical demands. Given a directional prediction, a $p < .05$, one-tailed, significance criterion ordinarily would be used. This criterion would apply to all rates explicitly mentioned as expected correlates of occupational physical demands (e.g., musculoskeletal disorders) or implicitly mentioned because the diagnosis was one element of a larger diagnostic category (e.g., the diagnosis "Arthritis" as a subcategory of musculoskeletal disorders). However, the observed correlations that would test the hypotheses either fell above the two-tailed critical value or below the one-tailed critical value. Adopting a two-tailed test for all correlations, therefore, did not affect any inference relevant to the study hypotheses and meant that a single criterion value could be applied to all correlations.

[8]With $r = .237$ as the reference context correlation, a focal correlation must exceed this value substantially to be considered significant. The standard deviation of the correlations in this study is SD = .134 after applying Fisher's r-to-z transformation (Hays, 1963, p. 530). The transformed value of the estimated contextual correlation, $r = .237$, is $z_{Fisher} = .242$. Given a one-tailed significance test, the critical value for the directional test was $z_r = 0.463$ (i.e., .242 + [1.65 * .134]). Transforming from z_{Fisher} back to r yields $r \geq .433$ as the critical value for inferring that a correlation significantly exceeds the contextual correlation.

[9]The quadratic term was a significant component of the predictive model in the earlier study only after personnel in pay grades E-7 through E-9 were dropped from the computation of back injury rates (Vickers et al., 1997). A similar outcome might occur for the wider range of measures considered here. Detailed analysis of this point was beyond the scope of this paper. The present objective was to identify a subset of illnesses as relevant indicators of the effects of occupational physical demands. Once the appropriate illnesses have been identified, more detailed analyses of those illnesses can be carried out. If it is assumed that the true functions relating illness rates to occupational physical demands are at least monotonically increasing, the linear approximation to those functions should be adequate to identify the relevant health criteria. The likelihood that this approximation is inaccurate is another reason for caution when interpreting the present quantitative estimates of the health effects of occupational physical demands.

[10]Qualitative trends in the data also support the claim that some cases of cellulitis are the result of performing physically demanding jobs. The multivariate predictive model for cellulitis includes PDRs, reaction time demand ratings, and reasoning demand ratings as predictors. The first two predictors had positive regression slopes; the third predictor had a negative slope. Twelve of 17 APV equations had positive slopes for PDR and reaction time; reasoning demands had a negative slope in 4 of 17 APV equations. There were no instances of negative slopes for PDR and reaction time or positive slopes for reasoning. The profile for cellulitis, therefore, parallels that of a prototypical APV variable.

[11]These ratings initially were selected to represent a general perceptual skill factor identified by Reynolds et al. (1992). Reaction time, defined as the ". . . (a)bility to give a fast response to a signal (sound, light, picture) when it appears" was the rating with the largest loading on this factor. Other ratings with substantial loadings were sound localization, vision, and speed of perception demands. These

other demands reflected occupational requirements for the ". . . (a)bility to identify the direction from which a sound originated," the "(a)bility to see objects clearly, even under low light conditions," and the "(a)bility to quickly and accurately compare letters, numbers, objects, pictures, or patterns" (Reynolds et al., 1992, pp. A-11-A-12). A high reaction time rating, therefore, implies that the occupation requires visual and auditory awareness of the work environment, the ability to identify key stimuli or patterns of stimuli in that environment, and the ability to react quickly to the signals implied by those patterns. This pattern of demands is a reasonable definition of the need for situational awareness on the job. Navy safety programs routinely emphasize the importance of situational awareness, so these indicate that ratings provide one means of quantifying the hazard in work settings.

[12]The argument that selection processes account for the relationship between reasoning demands and mental disease rates appears more reasonable at present than the alternative view that reasoning demands cause better mental health. However, the latter interpretation should not be ruled out completely, because working conditions can affect personality (Kohn & Schooler, 1973). If the relationship between reasoning demands and mental health is one instance of the effects of jobs on personality, the strength of the association between reasoning and mental health should increase the longer the person has been on the job. This position would be supported by evidence that the association between reasoning demands and mental demands was stronger for personnel in higher pay grades or for people who had been in the service longer. The hypothesis that the associations are stronger in personnel who have been in the U.S. Navy longer cannot be tested in the present data. The required health criteria are not available because the disease rates have not been broken down by pay grade. The association may be difficult to demonstrate even if present, because mental diseases are less common among older personnel. Analysis of age trends in the EPISYS database indicated that the rate for the overall ICD-9 category of mental disorders was 2021 per 100,000 person-years of observation for 20-24 year olds, but this rate dropped to 980 for 30-34 year olds and to 807 for 40-44 year olds. This trend probably reflects both normal maturation processes and the fact that personnel with mental health problems tend to be screened out when it is time for reenlistment.

[13]It may be difficult to determine whether adjustments are appropriate even if demographic variables are related to occupational physical demands. Adjustments would be appropriate to the degree that the correlations between occupational demands and illness rates are spurious. Spurious associations are a problem when a correlation is interpreted as indicating that one variable causes another. The correlation is spurious if it occurs because the correlated variables have one or more common causes (Heise, 1975). The common cause(s) then can account for at least some of the covariation between the measures. If so, the estimated effect of the presumed cause will be inflated by adding in the effects of the common cause.

If demographic attributes are related to occupational physical demands, determining which correlation is more likely to be spurious will be difficult. Consider the example provided by the relationships between age and accidents. Accident rates decline with age and pay grade. For example, in the EPISYS database, the accident rate drops from 1,714 per 100,000 person-years of exposure for sailors between 20 and 24 years of age to 899 for sailors between 30 and 34 years of age, then to 718 for sailors between 40 and 44 years of age. To the degree that age is an index of biological aging processes, older individuals would be expected to be more susceptible to accidents. The trend decline in accident rates with age is contrary to this expectation, but could be explained by assuming that age really is an index of decreased exposure to the hazardous elements of one's occupation. This interpretation would be reasonable given that older personnel are more senior and, therefore, less likely to be assigned the most physically demanding tasks in an occupation. The observed age-accident correlation would be spurious, because it would not indicate a causal effect of aging processes. Instead, age would correlate with illness rates only because age was related to the true cause of illness (i.e., the level of exposure to occupational physical demands). In this case, any estimate of the effects of occupational physical demands that controlled for age would be misleading because differences in illness that properly would be attributed to occupational physical demands would be assigned to age. The fact that the direction of association between age and accident rates is contrary to an aging process interpretation could be used to argue against such estimates, but the argument would not be definitive. Other interpretations of "age" exist that would make it appropriate to control for age effects when estimating occupational differences in illness. For example, age could be an indicator of knowledge and experience that reduce the risk of accidents. In this case, controlling for age could yield a better estimate of the effects of physical demands on health. However, in this case a second problem arises because reduced exposure and increased experience could be confounded. The confounding means that effect estimates would necessarily have lower precision of estimates than otherwise would be the case (Farrar & Glauber, 1967).

This example of the potential interpretive difficulties that could arise when a wider range of measures is examined is noted here to make the point that correlational data must be interpreted cautiously. Sound interpretation requires modeling of the pattern of associations between physical demands, demographic variables, and illness rates. Statistical modeling cannot entirely resolve the interpretation issues raised here, but it can provide clues regarding which models are most plausible (Glymour, Scheines, Spirtes, & Kelly, 1987). Modeling would provide a basis for more refined estimates of the effects of occupational physical demands on health.

It would be premature to assume that more extensive modeling will seriously diminish the estimated health effects of occupational physical demands. The mathematics of statistical adjustment procedures are such that the estimated effects would be substantially smaller only if a given demographic variable was strongly related to both occupational status and one or more illnesses. Whether that condition is met for one or more demographic variables remains to be determined. The point of the present comments is not that the estimated health effects of exposure to occupational physical demands must be refined. The point is that refinement may be needed and that the magnitude of the revision is uncertain.

The present margin of uncertainty in the health effects estimates is acceptable at this time. The study objectives were to establish that relationships existed that might be interpreted as effects of occupational physical demands and to provide initial estimates of the effects. The present estimates demonstrate sufficiently strong associations to justify an initial claim that these occupational demands affect health and that there is a need for further modeling efforts to estimate those effects with greater precision.

[14]Estimates of outpatient treatment rates are available from several prior studies. Doll, Rubin, and Gunderson (1969) reported 5.61 sick call visits per 1,000 crew members per day in a study of an attack cruiser. Rahe, Mahan, Arthur, and Gunderson (1970) reported rates of 9.6, 9.7, and 5.7 sick call visits per 1,000 crew members per day in a study of three cruisers. Rubin, Gunderson, and Arthur (1971) reported a sick call visit rate of 11.7 per 1,000 crew members per day in a study of a battleship. Nice and Hilton (1990) reported rates for destroyer tenders, submarine tenders, oilers, repair ships, and salvage ships. Data were reported by ICD-9 code for males and females separately. Using the data for males to provide the closest correspondence to the earlier studies, sick call rates for the ICD-9 categories analyzed in this paper totaled 318.7 visits per 1000 crew members per month (i.e., approximately 10.6 per day). The various rates reported in these studies translate to between 204,765 and 427,050 visits per 100,000 crew members per year. The total rate for the present study was 8,800 hospitalizations per 100,000 per year, thereby indicating that there were 23.3 to 48.5 times as many outpatient treatments as hospitalizations. In Nice and Hilton's (1990) data, accidents accounted for approximately 30% of the total number of visits. Applied to the range of outpatient rates estimated here, this figure would result in 61,430 to 128,115 cases per 100,000 crew members per year. If 10% of these accident cases result in duty limitations, the total number of cases involving unavailability for work would be 4 to 9 times the number of hospitalization cases (i.e., 6,143 to 12,812 outpatient cases vs. 1,385 hospitalization cases, cf., Table 1). Illnesses treated on an outpatient basis are milder than those requiring hospitalization, but the cumulative impact of outpatient treatment still will be substantial. The figures cited here are illustrative and must be interpreted cautiously. The estimates do not allow for differences between ship and shore illness rates and cover only some types of ships (i.e., cruisers, battleships, and aircraft carriers). Even with these limitations, the figures illustrate that ignoring outpatient treatment will significantly underestimate the cumulative illness burden.

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Appendix A. Multiple Regression Equations for Illness Variables

	Physical	Reaction Time	Dexter-ity	Reason-ing	Communi-cation	Cons-tant	R
Infections					-63.38	167.34	.580
Neoplasms	-13.81	-27.96	39.86		39.37	20.93	.639
Metabolism		-19.51				200.54	.372
Blood		-18.02			38.45	-10.15	.495
Mental	133.65		173.65	-276.64		1214.18	.665
Alc. Abuse	34.02	21.59	44.36	-57.31		122.13	.672
Alc. Intox.	133.54			-167.53		813.07	.714
Neurotic				-39.82	49.06	34.79	.550
Depression				-52.69	79.05	41.72	.455
Psychotic			24.32	-26.78		132.96	.396
Personality			90.54	-85.71		309.29	.441
Nervous System			39.89	-41.33		283.84	.476
Circulatory	23.80			-39.27		364.63	.463
Respiratory			61.41			284.79	.294
Digestive	45.40		91.26			360.01	.531
Inguinal	30.93					112.80	.594
Noninguinal			81.51			317.79	.352
Genitourinary		-108.72			179.47	-3.81	.603
Skin	37.33	18.69		-49.47		329.10	.654
Cellulitis	27.13	14.95		-24.54		90.12	.694
Noncellulitis			30.64			86.65	.283
Musculoskel.	108.54		104.99			218.58	.409
Arthropathy				[No Significant Predictors]			
Knee	31.98	24.66				47.46	.659
Other Joints	29.67	18.47		-45.30		232.10	.572
Discs/Spine	31.10					97.30	.553
Rheumatism	39.38					142.71	.475
Osteopathy	16.83		57.99	-46.30		212.61	.575
APV	238.91	181.62		-233.20		875.30	.782
F: Disloc.	32.68	18.81				-6.96	.597
F: Lower Limb	26.44	44.67	40.99		-57.91	99.01	.704
F: Neck	14.33	15.06			-22.72	73.52	.632
F: Skull	23.99	17.78				-45.55	.697
F: Upper Limb	29.87	27.37			-50.96	207.02	.673
Intracranial	17.99	12.71				6.92	.484
Internal	9.74	9.30				-8.30	.422
Late Effects	13.70		30.33	-44.81		124.35	.607
Head/Neck/ Trunk	24.45					26.42	.507
W: Lower Limb	6.69	13.06			-19.91	57.34	.621
W: Upper Limb	40.59	15.94				-72.98	.766
Sprain	26.86	49.35		-54.54		175.57	.649

Note. Entries are regression coefficients and the multiple correlations produced by stepwise multiple regression procedures (see pp. 12-13 for details). "F" indicates a fracture. "W" indicates a wound. See Table 1 for full names of the variables and the ICD-9 codes covered.

Appendix B. Estimation of High Risk Cutoff Values

Vickers et al. (1997) used the regression of back injuries on PDRs to estimate a PDR cutoff value for separating U.S. Navy enlisted occupations into high-risk and low-risk occupations. A high-risk occupation was defined as any occupation with a predicted illness rate significantly higher than the predicted illness rate for a low-risk reference occupation. Vickers et al. (1997) initially proposed PDR > 2.94 as the appropriate cutoff value for defining high-risk occupations.

Table B-1 places Vickers et al.'s (1997) proposed cutoff in perspective. The table shows how strongly different operational definitions of "illness" and "significantly higher" affect the cutoff computations. The cutoff value can move up or down depending on how these terms are defined.

Table B-1.

PDR Cutoff Values for High Risk Occupations for Different Assumptions

	Univariate Equation			Multivariate Equation		
	95%(1)	95%(2)	99%(1)	95%(1)	95%(2)	99%(1)
Accidents	2.50	2.78	3.87	2.33	2.58	3.56
Musculoskeletal	2.63	2.94	4.13	2.71	3.03	4.27
Inguinal Hernia	2.63	2.94	4.13	2.63	2.94	4.13
Cellulitis	2.61	2.91	4.08	2.59	2.89	4.05
Mean	2.60	2.90	4.05	2.57	2.86	4.00
Median	2.63	2.93	4.13	2.61	2.92	4.09
Cumulative Illness	2.32	2.57	3.53	2.22	2.45	3.34

Note. The high-risk cutoff value was computed as: Cutoff = PDR_{RJ} + $[(z_\alpha * SEE)/b_{PDR}]$. PDR_{RJ} is the rating for the reference occupation. z_α is the standard normal deviate for the significance criterion. SEE is the standard error of estimate for the regression of the criterion on PDRs. b_{PDR} is the slope for PDRs in the regression equation (cf., Table 4). Numbers taking the form "xx%(y)" indicate the significance level (95% or 99%) and direction of the significance test (one- or two-tailed).

Vickers et al.'s (1997) original cutoff (PDR ≥ 2.94) generalized from back injuries to other illnesses when high-risk was defined the same way. Column 2 of Table B-1 presents the results for univariate predictive models with $p < .05$, two-tailed, as the statistical criterion defining a significant elevation of the illness rate, and PDR = 1.00 as the reference occupation. The estimated cutoffs ranged from PDR = 2.78 and PDR = 2.94; three of the four values were within 0.03 of the original cutoff of PDR = 2.94.

The choice of the statistical criterion that defined a significant elevation of the illness rate strongly affected the cutoff value. Choosing $p < .05$, one-tailed, rather than $p < .05$, two-tailed, reduced the cutoff approximately 0.30 points relative to Vickers et al.'s (1997) suggested value. Choosing $p < .01$, one-tailed, increased the cutoff by

0.90 to 1.20 points compared to the earlier suggestion. Combining these two observations, the cutoff could differ by as much as 1.50 points depending on which definition of a significant elevation was used.

The cumulative health criterion affected the cutoff value. Other things equal, the cutoff obtained using the cumulative illness criterion was 0.31 to 0.65 points lower than the cutoff obtained with individual illness rates as the criterion.

Although not shown in Table B-1, the choice of a specific reference occupation also affected the estimation of the cutoff values. Table entries were computed using a hypothetical occupation with a PDR = 1.00 as the reference point. The lowest rating actually received by any occupation in the present sample was PDR = 1.60. Using that occupation as the reference point, all of the cutoff values would be 0.60 points higher than in Table B-1.

The cumulative impact of the full set of choices that must be made to operationalize the general definition of a high-risk occupation is substantial. The PDR cutoff values shown in Table B-1 ranged from 2.22 to 4.27. Adding another 0.60 points to the upper limit to indicate the effect of shifting the reference job from PDR = 1.00 to PDR = 1.60 extends the upper limit of the range to 4.87. The lower boundary of the range of possible cutoff values (PDR = 2.22) would classify 74.6% of entry-level U.S. Navy occupations as high risk; the upper boundary of the range (PDR = 4.87) would classify all occupations as low risk.

The present study shows that the problem of setting a PDR cutoff to identify high-risk occupations is a complex matter. The cutoff depends heavily on how the generic definition of high risk is operationalized. The resulting proportion of high-risk entry-level occupations in the U.S. Navy can range from 0% and as high are 75%. Statistics cannot resolve the uncertainty inherent in this categorization problem. The decisions needed to define high risk are the responsibility of policy makers who can assign values to different tradeoff options. Viewed in this light, the finding that Vickers et al.'s (1997) initial cutoff generalized from back injury to other illness criteria when the definition of high risk was held constant is important. This observation suggests that cutoffs can be identified reliably once high risk has been defined satisfactorily.

Impact of Health Criterion - Quality of Measurement Effect?

Table B-1 shows that more occupations will be classified as high risk if cumulative illness is the health criterion. The cutoff value for the cumulative illness criterion was approximately 0.30 points lower than the values obtained for individual criteria. This point is important because it implies that the simplest means of modeling the health effects of occupational physical demands will systematically classify more occupations as high risk than will less efficient models.

The effect of choosing a cumulative illness criterion to represent the health effects of occupational physical demands can be explained as an example of how important psychometric principles affect the modeling process. The proof of this statement has two parts.

The first part of the proof is a demonstration that cumulative illness is a more reliable dependent variable than any individual indicator. This condition holds if the working conditions and task activities comprising different occupations truly affect the health of people in those occupations. If so, occupational differences in illness rates are indicators of the physical wear and tear caused by these aspects of the occupation. It follows that occupational differences in illness rates provide a basis for estimating the magnitude of the wear and tear characteristic of each occupation. In psychometric terms, the illness rates are effect variables (i.e., variables that can be used to estimate the magnitude of an underlying cause by examining its observable effects; cf., Bollen & Lennox, 1989).

Viewing each of the relevant occupational differences in illness rates as effects of occupational physical demands is the basis for asserting that the cumulative illness composite is more reliable than the individual rates. If each illness in the composite has occupational physical demands as one causal influence that is a source of variance, then all of the effect indicators that were summed to create the cumulative illness composite share a common cause. Applying this model, the following reasoning leads to the conclusion that the cumulative illness measure will be more reliable than a single illness:

A. All other things equal, variables that share one or more causes in common will be correlated (Heise, 1975; Glymour et al., 1987).
B. The sum of a linear composite has variance equal to the sum of the variances for the individual indicators plus twice the sum of the covariances between them (Nunnally & Bernstein, 1994).
C. When the components of a linear sum have been chosen to represent a single construct, the reliability of the sum as a measure of that construct is equal to the proportion of total variance associated with the underlying variable (Cronbach, 1951). As the proportion of variance attributable to the underlying construct increases, the reliability of the measure increases (Nunnally & Bernstein, 1994, pp. 232-236).
D. The proportion of variance is higher when correlations between the individual components of the linear sum are larger. This condition will be met if the variables that are summed are strongly influenced by the underlying cause that is to be measured by the effect indicators. The latter point follows from the fact that the correlation between two effect indicators is the product of the strength of the causal paths from the underlying common cause to the two indicator variables (Bollen & Lennox, 1989; Glymour et al., 1987).

The preceding rationale applies to the cumulative illness index if that index is interpreted as an indicator of the wear and tear imposed by occupational physical demands. The correlations reported in this study establish that it is reasonable to regard those demands as causes of the four illnesses summed to produce the cumulative illness index. The strength of the correlations is an approximate index of the strength of the causal associations, so the linear composite should be a fairly reliable index of the cumulative wear and tear arising from occupational physical demands.

The second part of the proof shows that a more reliable criterion will produce lower critical values. The heart of this argument is the fact that reliable measures yield stronger correlations than unreliable measures. The standard formula embodying this fact is often referred to as a formula to correct for attenuation due to unreliability (Nunnally & Bernstein, 1994, pp. 256-258). The correction is

$$r_{xy}' = r_{xy}/\sqrt{(r_{xx} * r_{yy})} \qquad \text{(Equation B-1)}$$

which can be restated as

$$r_{xy} = r_{xy}' * \sqrt{(r_{xx} * r_{yy})} \qquad \text{(Equation B-2)}$$

In these equations, r_{xy}' is the correlation that would be obtained if measures were perfectly reliable. This correlation is sometimes referred to as the true population correlation. The simple r_{xy} is the correlation that is actually observed in the data when two measures are used to estimate the true correlation. In the typical case, the measures are less than perfectly reliable (i.e., $r_{xx} < 1$ and $r_{yy} < 1$), so $r_{xy} < r_{xy}'$.

Equation B-2 makes it clear that the size of the difference between r_{xy} and r_{xy}' depends on the reliability of the measures. As reliability of the measures increases, the observed correlation comes closer to the true correlation. This fact implies the slope of the regression of *y* on *x* will increase as the reliability of measurement of the criterion increases. The rationale for this statement is as follows:

A. If r_{yy} is the reliability of the dependent variable in a regression equation, r_{xy} will increase as the reliability of the criterion increases.
B. Larger r_{xy} means a smaller standard error of estimate (SEE; cf. Table B-1) for the regression equation because

$$SEE = [\sqrt{(1 - r_{yy}^2)} * SD].$$

C. Larger r_{xy} also means a steeper regression slope, b_{yx}, because $b_{yx} = [r_{xy} * (SD_y/SD_x)]$ (Nunnally & Bernstein, 1994, p. 141). If increasing reliability increases r_{xy} to r_{xy}', the steeper regression slope follows from $r_{xy}' > r_{xy}$ which implies $b_{yx}' > b_{yx}$.
D. Both (B) and (C) will lower the estimated cutoff value. The formula for the cutoff is: Cutoff = $PDR_{RJ} + [(z_\alpha * SEE)/b_{PDR}]$ (see Table B-1). Choosing a specific reference job fixes PDR_{RJ}. Setting the confidence level fixes z_α. Given these two choices, the critical value decreases as SEE decreases because the numerator of the second term of the equation decreases. Also, the critical value will decrease as b_{yx} increases in the denominator of the second term of the equation.

A more reliable criterion means that both conditions specified in (D) will occur, so the cutoff will be lower. It follows that the lower cutoff value for the cumulative illness index is a logical consequence of shifting from individual criteria to a composite criterion comprised of effect indicators of occupational wear and tear.

This derivation of the basis for the lower cutoff scores based on the cumulative criterion underscores the contingent nature of the cutoff value. The estimated cutoff value clearly depends on a number of technical considerations that should not be ignored in any application of the findings. Any actual cutoff values should be carefully justified by explicating the decisions that were made and the reasons for those decisions.

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13. ABSTRACT ***(Maximum 200 words)***

This study examined the health effects of performing physically demanding jobs. Hospitalization rates for 41 diseases were examined in a sample of 59 U.S. Navy entry-level enlisted occupations. As predicted, higher physical demand ratings (PDRs) were associated with higher rates of musculoskeletal disease ($r = .594$), accidental injury ($r = .627$), and inguinal hernia ($r = .594$). Cellulitis ($r = .600$), alcohol abuse ($r = .496$), and acute alcohol intoxication ($r = .643$) were strong PDR correlates that were not predicted. Musculoskeletal disease, accidental injury, inguinal hernia, and cellulitis are logical consequences of physical exertion. Taking these four diseases as the health effects of occupational physical demands, a highly demanding occupation (i.e., 90th percentile) will have one more hospitalization per year for every 124 sailors at risk than will a low demand occupation (i.e., 10th percentile).

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